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Characterization of aircraft emissions and air quality impacts of an international airport

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ABSTRACT

Beijing Capital International Airport (ZBAA) is the world's second busiest airport. In this study, the emissions of air pollutants from aircraft and other sources at ZBAA in 2015 were estimated using an improved method, which considered the mixing layer height calculated based on aircraft meteorological data relay (AMDAR), instead of using the height (915 m) recommended by ICAO. The yearly emissions of NO_x, CO, VOCs, SO_2, and $PM_{2.5}$ at the airport were 8.76×10^3, 4.43×10^3, 5.43×10^2, 4.80×10^2, and 1.49×10^2 ton/year, respectively. The spatial–temporal distribution of aircraft emissions was systematically analyzed to understand the emission characteristics of aircraft. The results indicated that NO_x was mainly emitted during the take-off and climb phases, accounting for 20.5% and 55.5% of the total emissions. CO and HC were mainly emitted during the taxi phase, accounting for 91.6% and 92.2% of the total emissions. Because the mixing layer height was high in summer, the emissions of aircraft were at the highest level throughout the year. Based on the detailed emissions inventory, four seasons simulation using WRF-CMAQ model was performed over the domain surrounding the airport. The results indicated that the contribution to $PM_{2.5}$ was relatively high in winter; the average impact was about 1.15 $\mu g/m^3$ within a radius of 1 km around the airport. Meanwhile, the near surroundings and southwest areas of the airport are the most sensitive to $PM_{2.5}$.

Introduction

With the development of economy, air transportation plays a significant role in global economic activities and air traffic has increased continuously over the last several decades (Vichi et al., 2016). From 1960 to 2005, global passenger air travel grew from 109 billion to 3.7 trillion passenger-km traveled (Stettler et al., 2011). Depending on a recent report of the Federal Aviation Administration (FAA), the number of passengers in aviation transportation is predicted to grow at an average annual rate of 2.5% by 2036 (FAA, 2016). With the rapid increase in air traffic demand, aircraft emissions as an important source of air pollution, have attracted widespread attentions (Masiol and Harrison, 2015; Stratmann et al., 2016). Aircraft engines produce NO_x, CO, HC, SO_2, CO_2, H_2O, PM and other trace compounds that are primary air pollutants or the precursor of secondary pollutants in the atmosphere (International Civil Aviation Organization (ICAO), 2011). Many studies have shown that air pollutants produced by a large airport could affect air quality near surroundings areas of the airport, even throughout the

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wider region (Rissman et al., 2013; Hudda and Fruin, 2016). Therefore, the environmental impact of airport emissions is still a significant issue to deal with for air quality management.

During recent years, most studies have been focused on the estimation of aircraft emissions and their impact. For example, Song and Shon (2012) estimated the emissions of greenhouse gases (CO_2, N_2O, CH_4, and H_2O) and air pollutants (NOx, CO, VOCs, and PM) from aircraft at four major international airports in Korea using the Emissions and Dispersion Modeling System (EDMS). Winther et al. (2015) presented an emission inventory of NO_x and PM for aircraft main engines, Auxiliary Power Units (APUs) and handling equipment, which was based on activity data and emission factors for the airport. Simonetti et al. (2015) calculated the total yearly emissions of NOx, CO, SOx, VOCs, and PM_{10} using the EDMS, and analyzed the characteristics of aircraft emissions, and they found that NO_x, SO_x and PM_{10} were mainly emitted during the take-off phases. Carslaw et al. (2012) estimated that the contribution of the emissions of NOx from Heathrow airport was 12–16 $\mu g/m^3$ at Oaks Road, which is a measurement site located at the south boundary of the airport. Song et al. (2015) simulated the impact of aircraft emissions on the O_3 concentration at and around three international airports using WRF-CMAQ model, and they found that aircraft emissions can have a noticeable impact on the concentrations of O_3 and NO_x in the airports and their surrounding areas. Yim and Stettler (2013) assessed the air quality impacts of UK airports using WRF-CMAQ model, and their results showed that more than 65% of the health impacts of UK airports could be reduced by jet fuel desulfurization and improved using GSE and APUs. However, almost all studies on airport emissions inventory estimates have only focused on emissions of aircraft, APU, and ground support equipment. There was little research on other sources of pollution at the airport. Moreover, most of these researches use one of the two methods to quantify aircraft engine emissions, one is using landing and take-off (LTO) cycle to estimate aircraft emissions, another is using the reference values recommended for aircraft emission calculations by the ICAO (2011). The LTO cycle defined by ICAO includes all activities near the airport that takes place below the atmospheric mixing height (altitude of 915 m) while the actual mixing height will change in different times and different locations. Therefore, these two methods that qualified the mixing layer height as 915 m will lead to high uncertainty of the estimation. Detailed and accurate estimations of airport emissions are essential for analyzing the characteristics of air pollutants and examining their impact on the air quality. On the other hand, despite the fact that more and more studies give attentions to aircraft emissions at ground level and air pollution in the vicinity of airports, there are still gaps for these studies, particularly in airports in Asia.

Here we focus on the Beijing Capital International Airport (ZBAA) which is the second busiest airport in the world based on passenger traffic (Airports Council International, 2016). The main aim of this study is to estimate a relatively accurate emission inventory, including the emission of aircraft main engines, APUs, ground support equipment, ground access vehicles, private vehicles, stationary sources, oil depot, and road fugitive dust. The daily changes in the height of the mixing layer are taken into consideration when calculating aircraft emissions. In addition, frequently occurred air pollution problems in Northern China have attracted widespread attention in recent years (Li and Han, 2015; Huang et al., 2015). We quantify the impact of aircraft emissions on regional air quality, especially in regard to $PM_{2.5}$. The obtained results could help government choosing locations of new airports and planning land use near airports, and thus provide the scientific basis for air pollution control in the airport.

1. Materials and methods

ZBAA is the busiest and largest airport in China with three main runways and is located approximately 25 km away from the northeast of the city center (Tiananmen Square) (Fig. 1) (CAAC, 2016). First, a detailed inventory including NO_x, CO, VOCs, SO_2, and $PM_{2.5}$ was calculated for aircraft and other sources in the airport. Then, the impact distribution of these emissions on regional air quality around Beijing was simulated using meteorological and air quality models.

1.1. *Aircraft emissions*

Aircraft emissions depended on the following factors: the numbers and types of aircraft, types of aircraft engines, fuel used, time spent on each operation phase, power setting, and distance of flight (Song and Shon, 2012). Traditionally, the research of emissions from aircraft and its impact could be generally divided into two parts: aircraft pollutant emissions occurring during the LTO phase (local pollutant emissions), and the non-LTO flight phases (*i.e.*, above 915 m and at cruise level) (ICAO, 2011). The effect of aircraft emissions for human activities at ground level was the most important and all airport related emission source activities were increasing rapidly (Tsilingiridis, 2009). Therefore the emissions of aircraft during the LTO phase were considered, excluding the cruise phase.

1.1.1. *Estimation methods*

According to standard LTO cycle, aircraft emissions were divided into four activities: taxi emissions occurring on the ground, take-off emissions occurring from 0 m to 304 m for departing planes, climb emissions occurring from 304 m to 915 m for departing planes, and approach emissions occurring from 915 m to 0 m for arriving planes (Rissman et al., 2013). However, the actual mixing height, which determined the time of the approach and climb, will change in different times. Therefore, this approach may result in inaccurate emissions estimation. In this study, we had made improvements to the computing method according to Eqs. (1) to (3) (Kurniawan and Khardi, 2011):

$$E_{ij} = \sum (\mathrm{TIM}_{jk} \times 60) \times (FF_{jk}/1000) \times (EI_{jk}) \times (NE_j) \tag{1}$$

E_{ij} emissions (g) of pollutant *i* (*e.g.*, NO_x, CO, or HC) for the aircraft type *j*.

EI_{jk} emission indices (g/kg of fuel) for pollutant *i*, in mode *k* (*e.g.*, take-off, climb, taxi, and approach) for each engine used on aircraft type *j*.

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